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Factors Affecting the Reproducibility of Small Solid-Propellant Batch-Check Rocket Motors for Quality-Control Purposes

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ABSTRACT

The effort expended and the initial results in evaluating a small solid-propellant batch-check motor are described. The intended use of the motor is to predict the performance of a full-size flight motor based on the measurement of a parameter W^*, relating the nozzle throat, the propellant weight and the motor chamber pressure integral. In all cases care was taken to control the measurement of these parameters. The motor uses a replaceable graphite-throat insert that undergoes a detailed inspection before testing. The insert is used only once, and the performance calculation is based solely on the prefire measurement. To determine the motor-chamber pressure integral, three independent pressure-measurements are made. The pressure transducers are calibrated on a high-accuracy Ruska dead-weight calibrator prior to use. Expected reproducibility between the pressure integral data of any channel for a given test is $\pm.05\%$. Initial motor evaluation indicates that when an aluminumized propellant is used the nozzle throat coating, during the early portion of the test, causes a significant change on the reproducibility of the motor. Data evaluation using aluminized propellant indicates a reproducibility of $\pm 0.25\%$ for motors within a propellant batch. A reproducibility of $\pm 0.10\%$ has been obtained from a non-aluminized propellant batch. At the present time the batch-check motor has not been used for its intended purpose because a correlation between the batch check and a full-size motor has not been made.

I. INTRODUCTION

In January, 1963, the Jet Propulsion Laboratory (JPL) initiated a development program to provide a solid-propellant rocket motor for a second generation SYNCOM satellite. This program, under the management of the Goddard Space Flight Center, was designated "Advanced SYNCOM." It was to result in a spin-stabilized, active repeater-communications satellite operating at synchronous altitude (22,300 miles) which would handle voice communication, teletype, and monochrome and color television signals.

In January, 1964, the Advanced SYNCOM communication program was redirected to include a number of experimental instruments in addition to the original communication instruments. This expanded program is the Applications Technology Satellite (ATS) program

and will result in a general purpose satellite capable of operation at synchronous altitude with experimental instruments in the areas of meteorology, communications, radiation, navigation, gravity-gradient stabilization and various engineering experiments. For these satellites to be placed in synchronous orbit, JPL will furnish a solid-propellant rocket motor to provide the final required-velocity increment at the apogee of the elliptical transfer orbit. This rocket motor is designated the JPL SR-28-1 (steel chamber) or JPL SR-28-3 (titanium chamber) rocket motor.

With the initiation of the JPL SR-28-1–3 motor program, plans were made to develop a small batch-check motor that would evaluate the ballistic performance of each batch of propellant cast. Initially the motor was to have a reproducibility sufficient to establish a certain range or limits by which it could determine the ballistic acceptability of the propellant. If the data should prove to be highly reproducible, the evaluation could be extended to essentially predicting the actual-flight motor performance from the batch-check data.

The evaluation of the batch ballistic performance would be based on the calculation of a "modified" characteristic velocity, a parameter defined as W*. The effort was not to obtain the exact W* value of the flight motor, but to obtain some reference value through which a correlation could be made. Within a batch, an initial goal was set to have the W* values from each motor tested agree within 0.25% of the batch-average value.

At the present time, ten batch-check motors are being cast per batch of propellant. Six of these charges are temperature conditioned at 60°F prior to static testing. Of the remaining four charges, two are temperature conditioned at 10°F and two at 110°F before testing.

II. MOTOR DESCRIPTION AND PREFIRE HARDWARE INSPECTION

During the initial design phase of the motor, the following considerations were made:

1. Presently available hardware would be used as much as possible
2. The casting and testing procedures would be made as simple as possible
3. All parts having a critical effect on the reproducibility of the motor would receive special attention, such as the igniter and nozzle-throat insert
4. The cost would be considered with respect to the data accuracy anticipated

From these considerations, the design was developed as shown in Fig. 1. The motor chamber consists of a mild-steel cylindrical tube 13 in. in length with an I.D. of 5.0 in. At each end of the chamber, special flanges are used to mount the head-end and nozzle-end closures. The igniter assembly, which is fastened to the reusable head-end closure with a lock nut, consists of an aluminum basket filled with 25 ALCLO pellets followed by a diaphragm and squib adapter. A Holex 1395 squib is used as the initiator.

The reusable nozzle-end closure is machined so a new nozzle insert may be bonded in position prior to each test. Three symmetrical holes drilled in the nozzle-end closure provide the necessary entrance to the motor chamber to monitor the pressure. The head-end and nozzle-end closures are sealed with the use of O-rings, positioned and held at the ends of the motor chamber with special V-clamps. The propellant is bonded to the motor chamber and is trimmed to a tubular shape with unrestricted ends.

The Graph-i-tite G material used in the nozzle-throat insert is put through a radiographic inspection at JPL to insure its acceptability. This material is supplied to a vendor who machines the inserts to within tolerances specified on JPL Print J 904 1799. Then the finished parts are immediately sent to the machine shop inspection area for a detailed inspection. During this procedure, the inserts are not only checked to see that they meet print tolerances, but each nozzle-insert-throat diameter is accurately measured to determine its initial average value so it can be used in the data-reduction calculations. Each nozzle insert is given a serial number, and the measured initial-throat diameter is correlated with this number.

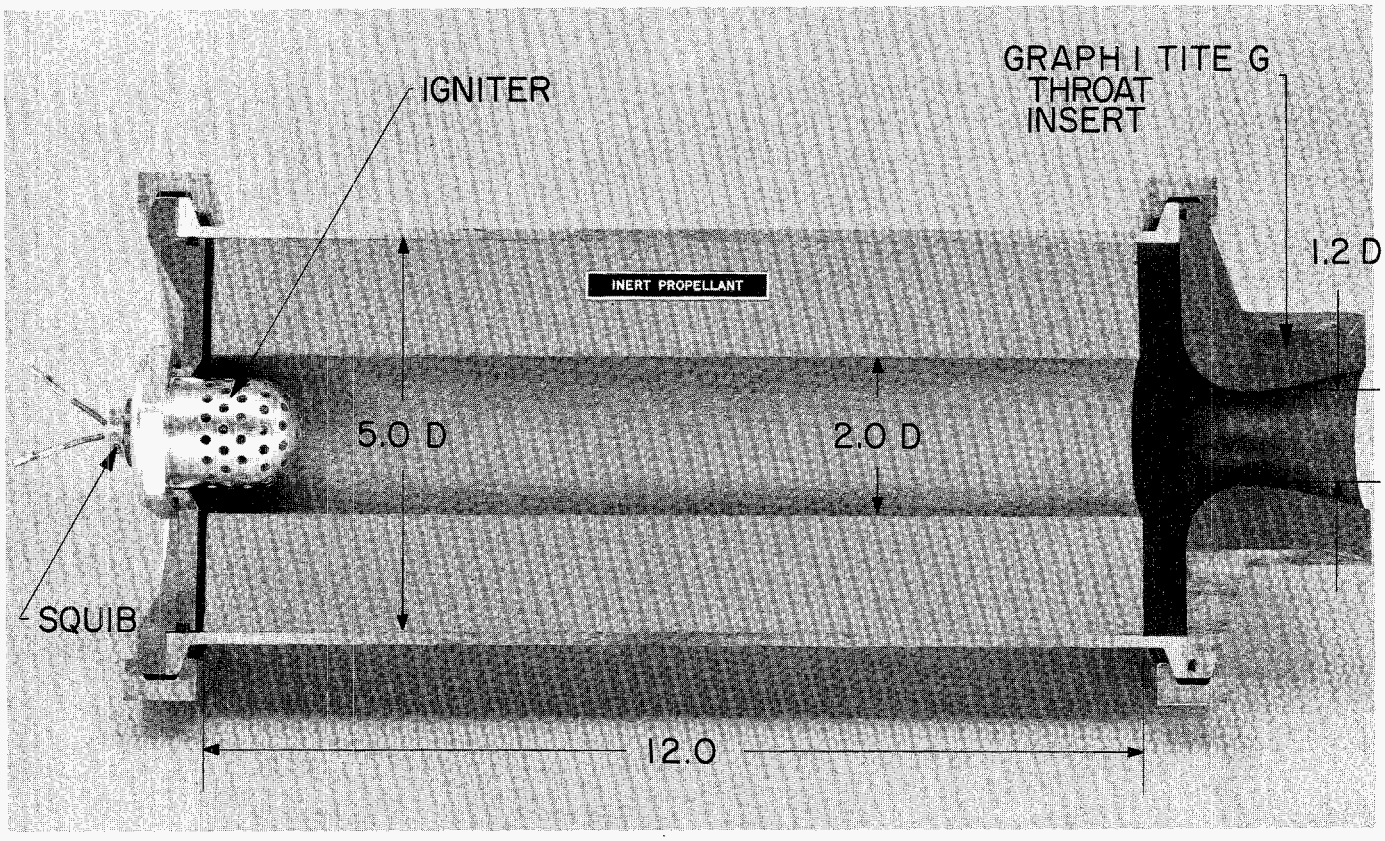

Fig. 1. Sectional photograph of the 5 × 13 batch-check motor

The inserts are then shipped to the JPL Edwards Test Station for assembly with the nozzle-end closure.

After arriving at JPL, the motor-igniter baskets go through an inspection similar to the nozzle-throat inserts only to see that they meet the tolerances specified on JPL Print J 904 1800. Then, they are sent to ETS for a static test. The Holex squibs are bought as an off-the-shelf item and are subject only to the quality-control standards established by the vendor.

III. MOTOR PROCESSING AND STATIC-TEST PREPARATION

The processing of the standard 5 × 13 batch-check motor is performed by using the JPL Standard Operating Procedure #236. This SOP states in detail the procedures, hardware, and measurements to be made during the processing phase of the motor.

In general, the motor parts such as the chamber and mandrel are cleaned and prepared prior to casting and then assembled according to JPL Print J 904 1791. The mandrel is an integral part of the head-end casting closure and results in forming the grain configuration at one end of the motor. The casting sleeve is added and the entire assembly is placed in a vacuum-casting chamber for the actual motor casting. The motor is vacuum cast and cured according to the instructions given in SOP #236. Following the casting procedure, the mandrel is pulled and the propellant is trimmed to the final desired configuration.

For pulling the mandrel, the motor assembly is placed on a special plate and the mandrel is pulled according to SOP #80, using the remote mandrel pulling device. Since

one end of the propellant grain has been formed with the mandrel, only a slight trimming cut is made at this end of the motor. From the other end, the propellant is trimmed, using a hand-operated lathe, until the desired 12-in. grain length is achieved. The core of the grain is left in the cast condition.

Prior to casting and after the final trimming, the motor chamber is weighed to obtain the final propellant weight. Before August, 1965, these assemblies were weighed using a Model B-210 Pennsylvania balance. After having problems with this scale, a Mettler P-10 was purchased for this particular weighing operation. The Mettler P-10, as stated by the manufacturer, has a readability of 1 gm and a reproducibility $< \pm 0.5$ gm. Tests were performed to establish the accuracy of the scale, using known standard weights, and, at this time, the scale can be conservatively rated at $\pm$ 0.05% within the weight range of use. A calibration system for the Mettler P-10 scale has been initiated to use check weights prior to and following each series of weight readings, and a detailed calibration curve for this scale is established at least once a month. It is believed that this system of checks and calibrations will help eliminate errors associated with the measurement of the propellant weights.

For the static test, the motors are assembled according to JPL Print J 904 1796. This procedure completes the motor assembly, with the exception of the squib installation. On all 5 × 13 batch-check motor firings, the squib is installed only after the motor has been strapped down in the test bay and is ready for ignition. Since the establishment of particular days of the week for casting ATS motors, a typical processing and static-test sequence schedule has been developed for the batch-check motor. The schedule presented in Fig. 2 essentially tells the technician on which day a certain operation should take place once a batch of propellant has been cast.

PROCESSING AND TEST SEQUENCE		SUN	MON	TUE	WED	THU	FRI	SAT	SUN	MON	TUE	WED	THU	FRI	SAT
PRECAST MOTOR PROCESSING (SOP 236)															
CAST 10 MOTORS PER BATCH (SOP 236)															
MOTORS IN CURE AT 140°F															
MOTORS REMOVED FROM CURE AND CONDITIONS AT 60°F															
MOTORS TRIMMED, MEASURED AND WEIGHED															
MOTORS IN TEMPERATURE CONDITIONING	CHARGES 1–6 (60°F)														
	CHARGES 7–8 (10°F)														
	CHARGES 9–10 (110°F)														
STATIC TEST OF CHARGES 1–6															
STATIC TEST OF CHARGES 7–10															

Fig. 2. Typical processing and static-test sequence

IV. MOTOR TESTING AND DATA REDUCTION

For a static test, the motors are removed from their respective temperature-conditioning ovens and mounted on a test table, as shown in Fig. 3. Since only motor-chamber pressure measurements are made, the required instrumentation consists of three 0–300 psig pressure transducers. The signal from each transducer is fed into a Dymex voltage-to-frequency converter and then into a MicroSADIC digital system. Therefore, for each test, three separate motor-chamber pressure-integral values are obtained. In addition, each signal is now paralleled into a second converter so a quick check of each voltage-to-frequency converter can be made; problems in this area had previously caused the loss of data.

Each pressure transducer is calibrated on a Ruska dead-weight calibrator, which has an accuracy within 0.04%, prior to its use on a sequence of static tests. The present procedure has been to use a set of three pressure transducers for three or four static tests, before having to recalibrate on the Ruska. The testing of the motors is therefore usually performed in sets of three. For example, out of the ten motors cast per batch, the first six at 60°F

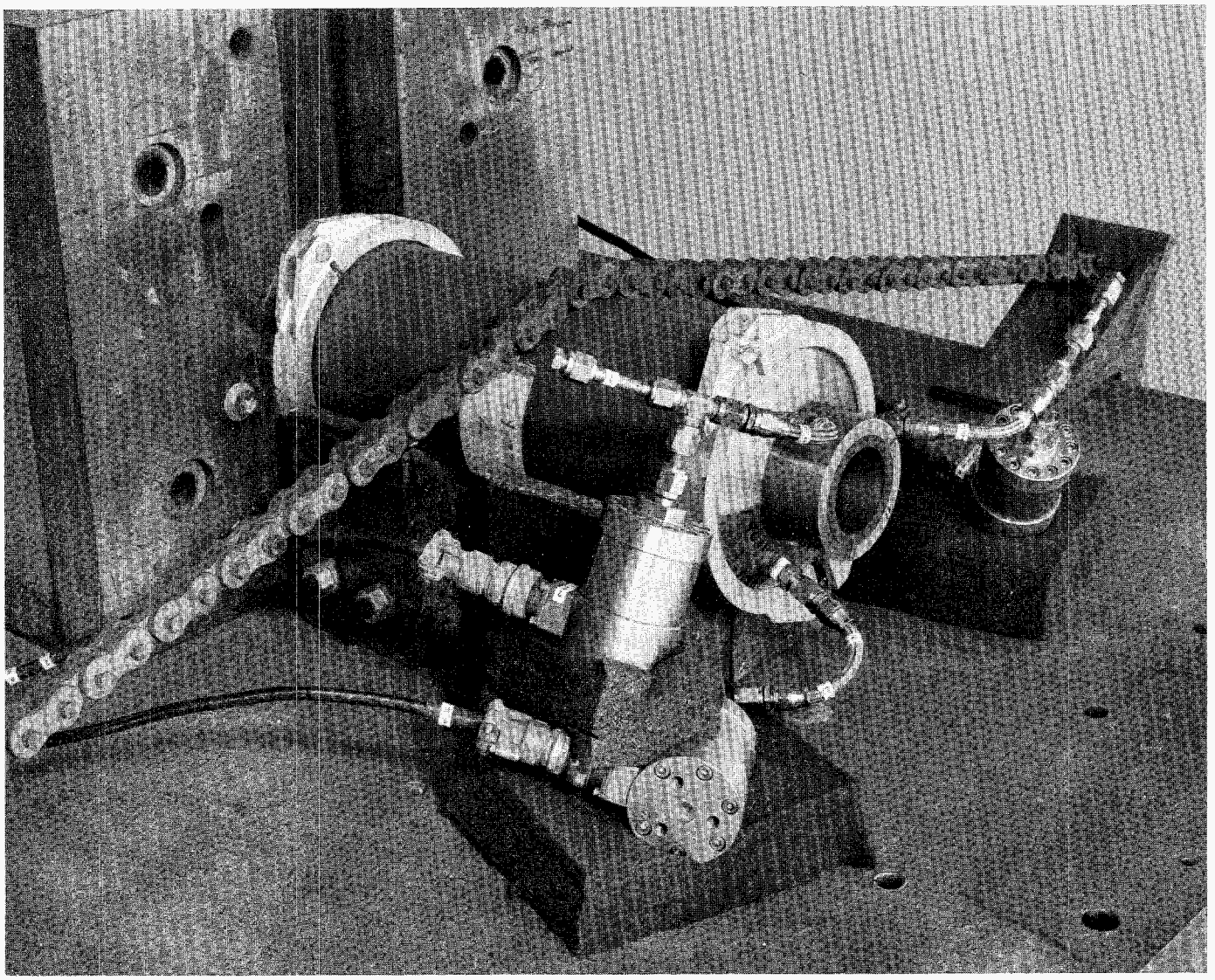

Fig. 3. Motor installation in the test bay prior to static test

are tested with two sets of three transducers each. The last four motors, two at 10°F and two at 110°F, are tested using the same set of three transducers. The reason for using the same transducer several times is the time consumed in calibrating a transducer on the Ruska (approximately 1 hr/gauge) becomes prohibitive. It is believed that the present procedure is a reasonable compromise between accuracy and effort.

Following the test, the magnetic data tape obtained during the run is supplied to the data reduction personnel at JPL to be reduced, using a standard batch-check motor data-reduction program. This program calculates W* in the following manner:

$$W^* = \frac{g_0 A_t \int_0^{t_r} P_c dt}{W_p}$$

where

t_r = total run time

g_0 = gravitational constant

A_t = initial throat area

P_c = motor-chamber pressure

W_p = loaded-propellant weight

Table 1. Performance-data summary of 5 × 13 batch-check motor

Batch number	Charge number	Run number	Test date	Conditioning temperature, °F	Propellant weight, lb	Initial throat diameter, in.	Chamber-pressure integral, psia-sec	Run W*, ft/sec	W*, % deviation	Batch W*, ft/sec
SY-070	373	315	11/5/64	60	12.232	1.201	1650.1	4913.3	0.200	
SY-070	374	316	11/5/64	60	12.232	1.201	1640.3	4882.5	0.429	
SY-070	375	317	11/5/64	60	12.216	1.201	1650.1	4914.8	0.229	4903.5
SY-071	2	330	12/1/64	60	12.236	1.200	1650.5	4905.5	0.174	
SY-071	3	331	12/1/64	60	12.203	1.200	1640.2	4887.3	0.198	
SY-071	4	332	12/1/64	60	12.221	1.200	1646.5	4898.1	0.024	4897.0
SY-072	2	333	12/8/64	60	12.263	1.200	1654.2	4902.5	0.056	
SY-072	3	334	12/8/64	60	12.298	1.201	1657.5	4905.6	0.007	
SY-072	4	335	12/8/64	60	12.249	1.201	1652.4	4907.7	0.049	4905.3
SY-073	2	336	12/8/64	60	12.238	1.201	1643.8	4887.3	0.134	
SY-073	3	337	12/8/64	60	12.214	1.200	1645.3	4898.1	0.087	
SY-073	4	338	12/8/64	60	12.243	1.200	1648.3	4896.2	0.047	4893.9
SY-074	2	339	12/15/64	60	12.234	1.200	1644.8	4885.4	0.055	
SY-074	3	340	12/15/64	60	12.247	1.200	1649.8	4897.4	0.190	
SY-074	4	341	12/15/64	60	12.274	1.200	1647.2	4881.5	0.135	4888.1
SY-075	7	344	12/22/64	60	12.231	1.200	1643.0	4879.4	0.125	
SY-075	8	345	12/22/64	60	12.247	1.200	1644.8	4882.7	0.058	
SY-075	9	346	12/22/64	60	12.262	1.200	1650.2	4894.5	0.183	4885.6
SY-253	2	295	9/24/64	60	12.229	1.200	1652.2	4906.8	0.160	
SY-253	3	296	9/24/64	60	12.207	1.200	1645.3	4902.6	0.075	
SY-253	4	297	9/24/64	60	12.218	1.200	1642.7	4888.1	0.222	
SY-253	5	298	10/8/64	60	12.247	1.200	1649.2	4894.8	0.085	
SY-253	6	299	10/8/64	60	12.241	1.200	1651.2	4903.2	0.087	
SY-253	7	300	10/8/64	60	12.256	1.200	1653.8	4904.9	0.122	
SY-253	8	301	10/20/64	60	12.258	1.200	1653.7	4905.6	0.136	
SY-253	14	308	10/30/64	60	12.230	1.200	1647.9	4899.6	0.013	
SY-253	15	309	10/30/64	60	12.245	1.200	1645.4	4886.9	0.245	
SY-253	16	310	10/30/64	60	12.236	1.200	1647.9	4896.9	0.041	4898.9
SY-253	9	302	10/20/64	10	12.236	1.201	1639.9	4871.6	0.087	
SY-253	11	304	10/26/64	10	12.235	1.201	1640.2	4877.1	0.024	
SY-253	12	305	10/26/64	10	12.224	1.201	1639.4	4879.0	0.064	4875.9
SY-253	13	306	10/26/64	10	12.226	1.201	(Data Lost)			
SY-253	10	303	10/20/64	110	12.245	1.200	1661.7	4932.5	0.015	
SY-253	17	311	10/30/64	110	12.254	1.200	1660.9	4929.9	0.039	
SY-253	18	312	10/30/64	110	12.260	1.200	1662.5	4932.3	0.010	
SY-253	19	313	10/30/64	110	12.236	1.200	1659.3	4932.5	0.014	4931.8
SY-254	1	321	11/13/64	60	12.280	1.200	1664.8	4929.8	0.093	
SY-254	2	322	11/13/64	60	12.203	1.200	1656.5	4934.3	0.002	
SY-254	3	323	11/13/64	60	12.225	1.200	1659.7	4939.1	0.095	4934.4
SY-255	1	327	12/1/64	60	12.232	1.200	1653.6	4916.4	0.187	
SY-255	2	328	12/1/64	60	12.225	1.200	1645.7	4896.5	0.220	
SY-255	3	329	12/1/64	60	12.236	1.200	1651.9	4908.9	0.033	4907.3
SY-257	1	354	2/11/65	60	12.249	1.200	1649.7	4893.9	0.255	
SY-257	2	355	2/11/65	60	12.197	1.200	1650.4	4914.5	0.165	
SY-257	3	356	2/11/65	60	12.185	1.200	1646.5	4910.9	0.090	4906.4
SY-258	1	365	3/5/65	60	11.793	1.200	1563.9	4819.7	0.081	
SY-258	2	366	3/5/65	60	11.815	1.200	1563.6	4811.2	0.095	
SY-258	3	367	3/5/65	60	11.800	1.199	1566.7	4819.7	0.082	

Table 1. (Cont'd)

Batch number	Charge number	Run number	Test date	Conditioning temperature, °F	Propellant weight, lb	Initial throat diameter, in.	Chamber-pressure integral, psia-sec	Run W*, ft/sec	W*, % deviation	Batch W*, ft/sec
SY-258	4	369	3/18/65	60	11.795	1.200	1563.6	4814.6	0.026	
SY-258	5	370	3/18/65	60	11.795	1.200	1563.7	4815.6	0.004	
SY-258	6	371	3/18/65	60	11.795	1.200	1563.9	4816.3	0.011	
SY-258	7	373	3/22/65	60	11.822	1.199	1568.4	4816.0	0.004	
SY-258	8	374	3/22/65	60	11.795	1.200	1562.1	4815.1	0.015	
SY-258	9	375	3/22/65	60	11.808	1.199	1565.9	4813.9	0.040	4815.8
SY-259	1	357	2/22/65	60	12.234	1.201	1648.1	4901.8	0.033	
SY-259	2	358	2/22/65	60	12.230	1.199	1649.3	4894.6	0.180	
SY-259	3	359	2/22/65	60	12.280	1.200	1661.2	4913.9	0.214	4903.4
SY-260	1	362	3/2/65	60	12.227	1.199	1644.3	4882.8	0.142	
SY-260	2	363	3/2/65	60	12.227	1.200	1647.3	4894.9	0.107	
SY-260	3	364	3/2/65	60	12.223	1.199	1647.5	4891.4	0.034	4889.7
SY-261	4	382	5/5/65	60	12.194	1.200	1645.3	4902.0	0.002	
SY-261	5	383	5/5/65	60	12.296	1.199	1661.1	4904.1	0.046	
SY-261	6	384	5/5/65	60	12.238	1.200	1648.7	4899.5	0.048	4901.9
SY-261	7	385	5/7/65	10	12.236	1.199	1641.8	4871.6	0.070	
SY-261	8	386	5/7/65	10	12.243	1.199	1649.7	4890.6	0.318	
SY-261	9	387	5/7/65	10	12.230	1.199	1643.3	4879.3	0.088	
SY-261	10	388	5/7/65	10	12.227	1.199	1639.4	4866.4	0.179	
SY-261	11	389	5/7/65	10	12.238	1.199	1641.6	4869.4	0.116	
SY-261	12	390	5/7/65	10	12.227	1.199	1641.9	4873.1	0.041	4875.1
SY-261	13	391	5/11/65	110	12.230	1.199	1667.7	4949.3	0.025	
SY-261	14	392	5/11/65	110	12.234	1.199	1666.9	4946.2	0.039	
SY-261	15	393	5/11/65	110	12.225	1.201	1664.2	4952.5	0.088	
SY-261	16	394	5/11/65	110	12.236	1.200	1660.9	4932.4	0.318	
SY-261	17	395	5/11/65	110	12.274	1.200	1673.1	4955.8	0.155	
SY-261	18	396	5/11/65	110	12.249	1.199	1671.1	4952.6	0.090	4948.1
SY-263	1	397	6/16/65	60	12.185	1.200	1646.0	4912.6	0.263	
SY-263	2	398	6/16/65	60	12.196	1.200	1642.2	4897.9	0.037	
SY-263	3	399	6/16/65	60	12.198	1.200	1643.0	4892.2	0.154	
SY-263	4	400	6/16/65	60	12.198	1.200	1642.2	4895.2	0.091	
SY-263	5	401	6/16/65	60	12.227	1.200	1648.1	4896.5	0.066	
SY-263	6	402	6/16/65	60	12.209	1.200	1646.6	4903.9	0.085	4899.7
SY-263	7	405	6/18/65	10	12.256	1.199	1644.0	4868.6	0.061	
SY-263	8	406	6/18/65	10	12.209	1.200	1634.4	4862.7	0.061	4865.6
SY-263	9	407	6/18/65	110	12.211	1.200	1656.1	4928.9	0.073	
SY-263	10	408	6/18/65	110	12.225	1.200	1655.8	4921.8	0.073	4925.3
SY-264	2	410	7/7/65	60	12.229	1.199	1652.4	4906.7	0.154	
SY-264	3	411	7/7/65	60	12.262	1.200	1652.4	4896.0	0.063	
SY-264	4	412	7/7/65	60	12.247	1.200	1651.9	4901.2	0.042	
SY-264	5	413	7/7/65	60	12.040	1.200	1621.4	4892.7	0.132	4899.1
SY-264	7	417	7/9/65	10	12.220	1.200	1641.3	4879.1	0.065	
SY-264	8	418	7/9/65	10	12.205	1.200	1636.4	4872.7	0.065	4875.9
SY-264	9	420	7/9/65	110	12.196	1.199	1654.9	4927.4	0.081	
SY-264	10	419	7/9/65	110	12.205	1.200	1652.6	4919.4	0.081	4923.4
SY-265	1	421	7/14/65	60	12.256	1.201	1650.6	4902.7	0.030	
SY-265	2	422	7/14/65	60	12.253	1.200	1656.5	4911.6	0.211	
SY-265	3	423	7/14/65	60	12.262	1.200	1654.9	4903.2	0.040	
SY-265	4	424	7/14/65	60	12.240	1.200	1651.6	4900.7	0.010	

Table 1. (Cont'd)

Batch number	Charge number	Run number	Test date	Conditioning temperature, °F	Propellant weight, lb	Initial throat diameter, in.	Chamber-pressure integral, psia-sec	Run W*, ft/sec	W*, % deviation	Batch W*, ft/sec
SY-265	5	425	7/14/65	60	12.271	1.200	1654.1	4896.3	0.100	
SY-265	6	426	7/14/65	60	12.269	1.201	1649.3	4892.9	0.171	4901.2
SY-265	7	427	7/15/65	10	12.266	1.200	1646.4	4875.8	0.262	
SY-265	8	428	7/15/65	10	12.240	1.200	1634.3	4850.3	0.262	4863.0
SY-265	9	429	7/15/65	110	12.251	1.199	1664.7	4933.4	0.149	
SY-265	10	430	7/15/65	110	12.249	1.200	1658.6	4918.7	0.149	4926.1

This program also calculates other parameters, such as K_n and the burning rate, but these are not used for the present batch-check-motor evaluation. All the calculated values of W^* are based solely on the prefire throat-diameter measurement. From preliminary tests, it was decided the error associated with the reproducibility of the throat erosion could be tolerated.

An optional data-reduction program has been written that supplements the one just described. This program takes the three motor-chamber pressure-integral values obtained during each test and calculates the percent deviation of each channel from the test-average value.

In addition, it accumulates all charges of one batch at a particular motor-conditioning temperature and calculates a batch W* value with a percent deviation of each charge used in obtaining the batch-average value. With the use of this program, a summary of the data obtained to this date is tabulated and presented in Table 1.

V. MOTOR-PERFORMANCE EVALUATION

To initially evaluate the motor performance, a reference batch (SY-253) of 18 charges was cast and static tested. These motors were tested at various times and under various conditions indicated by the test dates and motor-conditioning temperatures. All the data at any particular temperature fell within the desired 0.25% range.

Three pressure-time curves have been plotted in Fig. 4 and are representative of the motor performance at each conditioning temperature. An evaluation of this batch at the various temperatures indicates a total peak motor-chamber pressure variation of approximately 28.0 psia and a total run-time variation of approximately 0.7 sec. The average W* values at each motor-conditioning temperature of batch SY-253, and all other batches that have data at these temperature values, have been plotted in Fig. 5. With the exception of one data point, they all fall within 0.25% of the average value at any of the three conditioning temperatures.

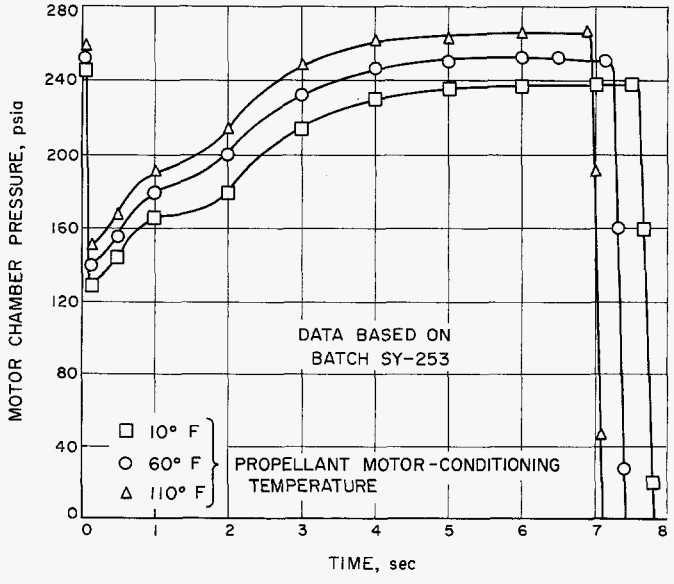

Fig. 4. Motor pressure–time curves

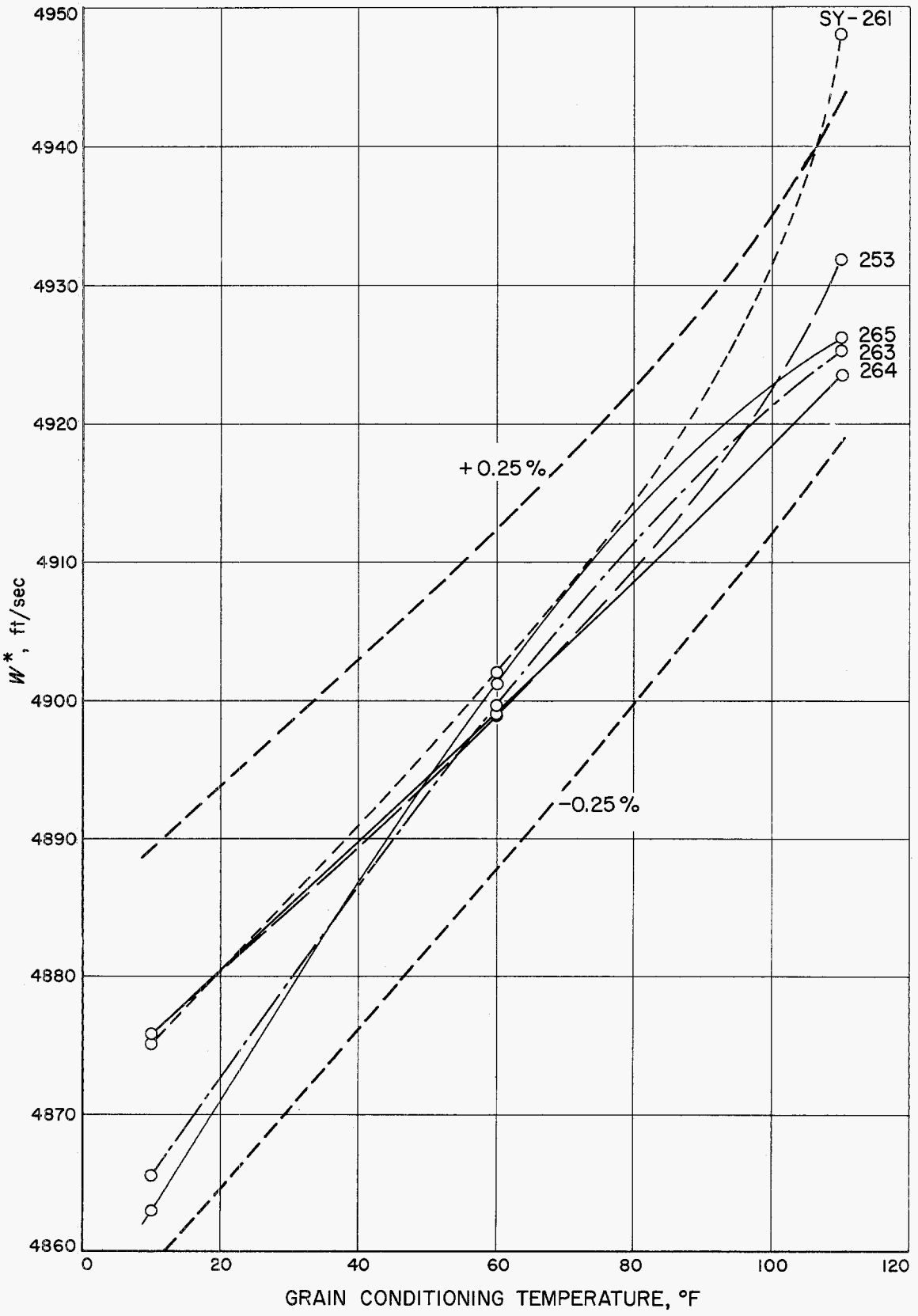

Fig. 5. Motor-performance variation with motor-conditioning temperature

Of the other batches presented in Table 1, a majority of the charges within a batch and at a particular conditioning temperature fall within the desired 0.25% range. On individual occasions, however, various charges will definitely be out of this range, such as charge 374 of batch SY-070 and charge 8 of batch SY-261. Following this initial evaluation, several investigations were initiated to find reasons for this seemingly random error. The solution might also reveal additional information about the random characteristics of the remaining data.

Assuming the propellant-weight measurement and nozzle-throat diameter measurement with its associated erosion would not be sufficient to produce this situation; an investigation was started to determine the extent of the reproducibility of the nozzle coating. To make a quick check of this condition, a batch of non-aluminized propellant was cast, and nine charges were tested at a motor-conditioning temperature of 60°F. The results are listed in Table 1 as batch SY-258. Based on the results from this batch, which shows not one charge deviated more than 0.1% from the batch average W* value, one would conclude the nozzle coating does make a substantial contribution to the reproducibility of the motor.

In addition to the non-aluminized propellant-batch results, a digital computer program for the IBM 1620 was developed to compare the accumulated motor-pressure integral of two tests. Because only several charges were tested under similar conditions, the choice of tests to compare became quite limited. Of the complete list, four tests were chosen, one pair to represent an extreme situation of the nozzle-coating problem and another pair to show its nominal effect. The results of this comparison are shown in Fig. 6. An evaluation of the extreme case shows a rapid accumulated difference during the first 2 sec of motor operation and then a nominal change from 2 sec to the end of the run. This evidence, plus oscillograph records recorded during a test, shows the nozzle coating is only a problem during the first 2 sec following ignition. Beyond this time, the insert has become hot enough so the material will not adhere to the insert. Since the two cases are extremes of the data, the remainder of the motors will probably be between these two cases. The results of this investigation also indicate that the nozzle coating does contribute to the reproducibility of the motor.

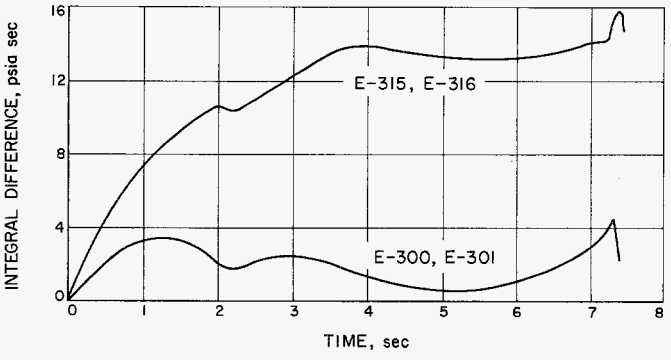

Fig. 6. Motor chamber-pressure integral comparison

After some effort had been put into the study of the nozzle coating, additional checks were made on the weight data, nozzle-throat diameter-measurement procedure, and instrumentation. This effort revealed that, during the time period these motors were tested, instrumentation problems occurred with the replacement diaphragms for the pressure transducers, and a random problem with a voltage-to-frequency converter was detected and solved. The procedure for measuring and inspecting the nozzle throat inserts proved adequate, and a weighing error associated with the Pennsylvania scale was determined. The purchase of the Mettler P-10 scale will hopefully eliminate further weight problems.

To date, an evaluation of all the data reveals that a motor reproducibility of better than ± 0.25% within a batch should not be expected. With this range of reproducibility as a criterion, all of the batch W* values at 60°F have been plotted in their casting sequence (Fig. 7). It is quickly noticed that only two motors fall outside this range. Therefore, with the present reproducibility, it is believed that, if the batch-check motor

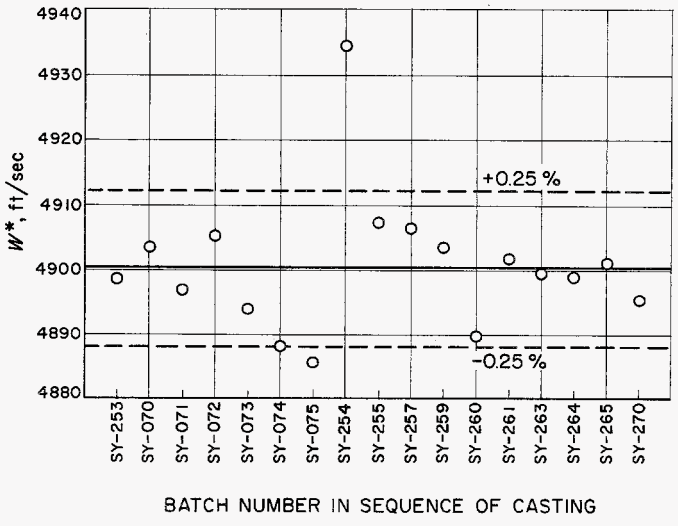

Fig. 7. Summary ot performance from motors conditioned at a temperature of 60°F

data continue to fall within this ± 0.25% range, no real effort could be made to predict the actual-flight motor performance, but a good range of motor-propellant ballistic-performance acceptability will have been established.

It is believed that the care taken in measuring the motor-propellant weight, in attempting to keep the initial-throat area and its associated erosion as constant as possible, and in placing emphasis on the accuracy of the instrumentation have been the major factors contributing to the data results. The problems associated with the nozzle-throat coating definitely contribute to the reproducibility of the motor, and, on the basis of the data obtained to date, a much better reproducibility would be expected if the problem did not exist. The results presently indicate that any additional refinement of the procedures for measuring the nozzle-throat insert, the propellant weight, or the accuracy stressed on instrumentation would not yield any significant results in light of the reproducibility of the nozzle coating.

At this time, approximately one-half of the expected number of 5 × 13 batch-check motors have been fired for this program. A continuing effort will be made to predict the actual performance of the flight motor and to cope with the nozzle-coating problem. If at all possible, the correlation with the flight motor will be attempted at the time the flight motor is qualified.